Scandinavian Journal of **Infectious Diseases**

Supplementum 11

Uppsala 1978

Isolation Care of Infection-Prone Burn Patients

By Ulrika Ransjö

1978

ISSN 0300-8878

Distributed by The Almqvist & Wiksell Periodical Company, Stockholm, Sweden

Scandinavian Journal of Infectious Diseases
Supplementum 11
Distributed by the Almqvist & Wiksell Periodical Company, Stockholm, Sweden

ISOLATION CARE OF INFECTION-PRONE BURN PATIENTS

Akademisk avhandling
som för avläggande av medicine doktorsexamen vid Uppsala universitet
kommer att offentligt försvaras i Akademiska sjukhusets aula
onsdagen den 10 maj 1978 klockan 09.15

av

ULRIKA RANSJÖ
med.lic., Värml.

ISSN 0300-8878
Uppsala 1978

ABSTRACT

An experimental and clinical study of spread of colonisation between burn patients, and their susceptibility to infection, was performed. Burn patients' polymorphonuclear neutrophil granulocytes (PMN) functioned poorly, particularly during the second week after injury which coincided with maximum growth of bacteria in the burn wound. Patients with large burns often dispersed *S. aureus* and *Ps. aeruginosa* but also beta-hemolytic *Streptococcus* to the air of their rooms. Airborne transfer of these bacteria was practically eliminated by nursing in single isolation rooms with plenum ventilation. In such rooms, cross-contamination was carried mainly via clothes. Patients with small burns sometimes were important sources of such contamination although they dispersed little bacteria to the air. A thorough change of barrier dress after close contact nursing delayed the first exogenous *S. aureus* colonisation until after the time of greatest impairment in PMN functions. A further reduction in cross-contamination would be possible with barrier garments impermeable to fluids and bacteria on points of contact, as shown in experiments with plastic apron as protective dress. Measurements of penetration through fabrics of particles suspended in air, commercially used, did not correlate to the performance of garments made from the fabrics in experimental nursing and clinical use. Bacteria were shown to penetrate fabrics through rubbing, particularly when wet where the microcolonies present on the cloth were separated into smaller units. An instrument was designed which measured such penetration, and was used to select fabrics for barrier garments. Tightly fitting barrier garments increased the dispersal of bacteria from clothes worn underneath them. The wearing of barrier garments should therefore be restricted to close contact nursing. An open-roofed plastic patient isolator was designed and built. It did not appreciably reduce cross-contamination and gave psychological and practical problems. It seemed not to be a realistic alternative to better protective garments in isolation rooms.

From the Institute of Clinical Bacteriology, the Department of Plastic Surgery, and the Department of Infectious Diseases, Uppsala University Hospital, Sweden

Isolation Care of Infection-Prone Burn Patients

By Ulrika Ransjö

Uppsala 1978

UNIV.
LEIDEN
BIBL.

ABSTRACT

An experimental and clinical study of spread of colonisation between burn patients, and their susceptibility to infection, was performed. Burn patients' polymorphonuclear neutrophil granulocytes (PMN) functioned poorly, particularly during the second week after injury which coincided with maximum growth of bacteria in the burn wound. Patients with large burns often dispersed *S. aureus* and *Ps. aeruginosa* but also beta-hemolytic *Streptococcus* to the air of their rooms. Airborne transfer of these bacteria was practically eliminated by nursing in single isolation rooms with plenum ventilation. In such rooms, cross-contamination was carried mainly via clothes. Patients with small burns sometimes were important sources of such contamination although they dispersed little bacteria to the air. A thorough change of barrier dress after close contact nursing delayed the first exogenous *S. aureus* colonisation until after the time of greatest impairment in PMN functions. A further reduction in cross-contamination would be possible with barrier garments impermeable to fluids and bacteria on points of contact, as shown in experiments with plastic apron as protective dress. Measurements of penetration through fabrics of particles suspended in air, commercially used, did not correlate to the performance of garments made from the fabrics in experimental nursing and clinical use. Bacteria were shown to penetrate fabrics through rubbing, particularly when wet where the microcolonies present on the cloth were separated into smaller units. An instrument was designed which measured such penetration, and was used to select fabrics for barrier garments. Tightly fitting barrier garments increased the dispersal of bacteria from clothes worn underneath them. The wearing of barrier garments should therefore be restricted to close contact nursing. An open-roofed plastic patient isolator was designed and built. It did not appreciably reduce cross-contamination and gave psychological and practical problems. It seemed not to be a realistic alternative to better protective garments in isolation rooms.

Digitized by the Internet Archive
in 2026

https://archive.org/details/IA41548924_0016

This thesis is the summary of the following papers:

I. Neutrophil leukocyte functions and wound bacteria in burn patients.
U. Ransjö, A. Forsgren and G. Arturson
Burns 3, 171-178, 1977

II. Attempts to control clothes-borne infection in a burn unit:
1. Experimental investigations of some clothes for barrier nursing.
A. Hambraeus and U. Ransjö
Journal of Hygiene 79, 193-202, 1977

III. Attempts to control clothes-borne infection in a burn unit:
2. Clothing routines in clinical use and the epidemiology of cross-colonisation.
U. Ransjö
Submitted for publication

IV. Attempts to control clothes-borne infection in a burn unit:
3. An open-roofed plastic isolator or plastic aprons to prevent contact transfer of bacteria?
Submitted for publication

V. An instrument for measuring the bacterial penetration through fabrics used for barrier clothing.
U. Ransjö and A. Hambraeus
Submitted for publication

The papers will be referred to by their Roman numerals.

CONTENTS

	sid
INTRODUCTION	7
AIMS OF THE PRESENT INVESTIGATION	11
MATERIALS AND METHODS	13
RESULTS	19
Neutrophil leukocyte functions and wound bacteria	19
Experimental investigations of some clothes for barrier nursing	21
Epidemiology and clothing routines in clinical use	23
Isolator and aprons	26
An instrument for measuring bacterial penetration through fabrics	28
DISCUSSION	30
CONCLUSIONS	38
ACKNOWLEDGEMENTS	40
REFERENCES	41

INTRODUCTION

Infection causes at least 50 % of the deaths among burn patients today (29). Colonisation of the burn wound is usually established by the second week after injury (73). The most important microorganisms causing infection are *Staphylococcus aureus*, *Streptococcus* species and *Pseudomonas aeruginosa* (51, 73, 79).

There are several reasons why burn patients are sensitive to infection (56). Firstly, the integument as an important barrier against microorganisms is lost. Secondly, the burn wound would seem an ideal substrate for bacterial growth. Thirdly, the microcirculation in the burn wound is obstructed, so that the humoral defences against infection might not reach the wound. Fourthly, there is evidence that these circulating defences are impaired in burn patients.

Neutrophil leukocyte functions

The importance of the relationship between phagocytes and wound bacteria in the establishment of infection has long been realized (50). The polymorphonuclear neutrophil leukocytes (PMN) of infected patients are normally activated into rapid locomotion towards bacteria and killing of them (31, 37, 60). Patients with defects in such PMN functions have been shown to succumb more easily to bacterial infections, particularly with gram-positive organisms (61, 70).

Many workers have found severe defects in the neutrophil leukocyte functions of patients with large burns (1, 9, 32, 74). The mechanisms behind the defects in burn patients' PMN functions are not quite clear. Serum factors, such as complement C3, are depleted in the first few days post burn (5). Disturbances in serum electrolyte contents have been shown to affect leukocyte activities (27, 71). Factors in the serum of burn patients may be inhibitory to leukocyte functions (76). These serum factors might be derived from products of the burnt tissue (6). Bacteria in the burn wound, such as *Ps. aeruginosa* (57, 67) or *S. aureus* (65) might also affect PMN functions.

That the PMN functions could be correlated to the outcome of burn patients and the prognosis of septicemia in such patients has been shown (1, 74). Few attempts have been made, however, to correlate the time of impairment in PMN functions to clinical state, wound bacteria, treatment and sensitivity to infection.

Colonisation of the burn wound

The differentiation between colonisation and infection of a wound with bacteria is difficult, particularly in the burn patient (51). The usual signs of fever and leukocytosis may be lacking or be caused by the burn injury *per se*. The amount of bacteria necessary to establish an infection with clinical signs of inflammation in the burn patients is not known. In experimental infection, the infective dose of *S. aureus* in injured skin of healthy persons appears to be about a thousandfold less than that in intact skin (55). As the burn patients' defences against infection are impaired, the infective dose in the burn wound is probably even lower.

Sources of colonisation

Burn patients are not only sensitive to bacterial infection, but also prolific sources of bacteria. Patients are the most common source of cross-colonisation in the burn units (33). Exogenous colonisation rates of 70-75 with *S. aureus*, around 30 % with *Str. pyogenes* and 30-60 % with *Ps. aerugi-nosa* are not uncommon in isolation wards for burn patients, whether patient are treated by exposure (73, 79) or with occlusion bandages (23, 81). These data could be compared to the wound infection rates of about 7-10 % which are usual in most general surgical wards (3, 12, 19).

Isolation care

After Colebrook's pioneer work (26), there has been general agreement that burn patients should be nursed in isolation wards. Some investigations have found isolation wards of value in the protection of surgical patients again infection (69), whereas others have been unable to demonstrate this effect (77). Barrier nursing in isolation wards is not enough to prevent cross-contamination between burn patients (23, 33). Attempts to diminish the transfer of bacteria from patient to patient in wards by increasing the

ventilation have not given the desired results (45). Airborne dispersal of bacteria-carrying particles causes only a small proportion of the transfer of bacteria between the rooms of burn patients (36). The major transfer is probably clothes-borne, both in burn units (35) and in general wards (46).

Many have attempted to improve clothes for protective nursing and surgery in order to reduce the dispersal of bacteria from staff (2, 13, 78). Most of this work has been experimental. Bacteria emitted from staff are of relatively minor importance, at least in wards with patients who are heavily infected and potential sources of infection (33). Cross-contamination from patient to patient via nurses' clothes, which may be far more important, is a problem that remains to be solved.

Fabrics for barrier garments have usually been selected on the basis of air filter tests (e.g. 59). Very little has been done to correlate these tests with the way the clothes perform in clinical use.

As to the fit of protective garments, several investigators have maintained that a closer garment would permit less spread of bacteria from staff than a more loosely fitting dress (13, 15, 39, 78). How the fit of a garment affects the clothes-borne spread of bacteria from patient to patient is not known.

Isolators (IV)

To prevent clothes-borne cross-contamination, a bacteria-tight layer must probably be inserted between nurse and patient. This could be done by enclosing either the nurse (59) or the patient (20) in an isolator. The technique of plastic isolators has been in use for many years in the rearing of gnotobiotic animals (44). It has been applied for ultra-clean surgery (25) and in the care of immunosuppressed patients (16). Some trials of isolators in the nursing of burn patients have also been made. The burn patient would need both protective isolation, since he is very sensitive to cross-infection (e.g. 56) and source isolation, since he is also a heavy disperser of microorganisms (34).

Two main principles have been used for burn patient isolators:

a. the "bubble", where the burn patient is enclosed in a plastic bubble provided with half-suits for nurses and with diffuse ventilation. This has been tried both as a source isolator (7) and as a protective isolator (52). In those investigations it seemed to prevent against cross-contamination with *Ps. aeruginosa*, but to have very little effect on the colonisation of the burn patient with *S. aureus*. No attempts to differentiate between endogenous and exogenous colonisations were made, however.

b. the "life island" is an isolator with more or less closed plastic walls and with ultra-clean air. In such a bacteria-controlled environment, a reduction of the cross-infection rate to 10 % in the nursing of burned children has been achieved (20). In that investigation, however, many other factors were included, such as early excision and grafting of the burn wounds (21) and topical chemotherapy. It is therefore difficult to evaluate the importance of this isolator in the low cross-colonisation rates.

Patient isolators are costly and staff-demanding. Before they are generally accepted, we must know if as good results can be achieved by simpler means.

AIMS OF THE PRESENT INVESTIGATION

1. To identify burn patients in need of protective isolation

Further reduction of exogenous colonisation rates in burn patients would probably demand great effort. Such efforts could only be made with a limited number of patients. Some means of selecting these patients would therefore be needed. It would be desirable to know in some detail which burn patients are most sensitive to infection, and at which time after the injury. The neutrophil leukocyte functions could be a useful gauge of this.

In paper I, the chemotaxis and bactericidal capacity of PMN from adult burn patients have been measured during the first three weeks after injury. These PMN functions have been related to the amounts of bacteria in the burn wounds and to the clinical course of the patients.

Paper III is a clinical epidemiological study where the colonisation rates with *S. aureus*, beta-hemolytic streptococci and *Ps. aeruginosa* have been correlated to burn size and time after injury.

2. To identify burn patients in need of source isolation

It is well known that burn patients disperse *S. aureus*, the larger the burn surface the larger the amount (34). Do the dispersers also give rise to more cross-colonisation with *S. aureus* and other microorganisms?

Paper III deals with the relationship between burn size, dispersal and sources of colonisation with *S. aureus*, beta-hemolytic streptococci and *Ps. aeruginosa*.

3. To improve clothes and clothing routines for barrier nursing

If the main spread of contamination between patients is by clothes-borne contact, the obvious way to combat this spread would be to improve clothes and clothing routines. In clothes, two factors may be important, the fabric they are made of and the way they are tailored.

The standard way to examine fabrics is to test their permeability to aerosols and fluids and to check their pore size. Paper II is an experimental

study containing experiments with some types of fabrics intended for barrier garments and with three different tailorings of one fabric.

Paper III contains clinical trials of clothes and clothing routines previously tried experimentally.

A new instrument has been developed for testing the barrier properties of fabrics with bacteria-carrying particles. The results of this are reported in Paper V.

4. To obtain some experience with a patient isolator

Some trials with patient isolators for burn patients had given favourable results, as reported above. The mechanisms by which these results were achieved were not clear.

In paper IV, results of development, experimental and clinical experience with an open-roofed plastic isolator are reported. The effects of the isolator on source and protective isolation have been evaluated and compared to the results with nursing in plastic aprons.

MATERIALS AND METHODS

The ward - design and ventilation (III, IV)

The studies were performed in a burn unit with six plenum ventilated isolation rooms. The ventilation rate of the rooms was approximately four air changes/hour (36). The air-locks functioned as designed on 30-40 % of the occasions, that is as a barrier between patient room and corridor.

Patients and patient care

Burn patients of all ages were admitted to the unit, usually immediately after injury. The burn size distribution and length of stay of the patients in the ward are shown in Fig. 1 a and b. In the following, burns of 30 % of body surface area or more are referred to as large. Patients were treated by exposure, early excision and grafting. No topical chemotherapy was given. The antibiotics most commonly given were benzylpenicillin, cloxacillin and gentamicin. Fluid therapy with complete parenteral nutrition, supplementary electrolytes and gammaglobulin were used for larger burns.

Fig. 1 The burn size distribution and the length of stay of the patients.

Bacteriology

Wounds (I, III, IV). Semi-quantitative wound cultures were taken from constant sampling sites at every five per cent of burn wound surface area twice a week. In the clinical study (III) only colonisations during the admission period were considered.

Air (II, III, IV). Blood agar settle plates were exposed in patients' rooms daily. Bacterial contamination of air during mock nursing was determined with a high-volume slit sampler (II, IV). A patient was considered a disperser if a strain from his wound was found on a settle plate, even in single colony-forming units (c f u).

Clothes (II, IV). Contamination of clothes was determined by a wash method (35).

Staff nose and throat cultures were made once a week.

Identification. Plates were cultured aerobically. Bacteria were identified according to current methods. Isolates of *S. aureus* and *Ps. aeruginosa* were phage-typed (14, 68). Isolates of beta-hemolytic *Streptococcus* were serogrouped (22).

Polymorphonuclear leukocyte functions (I)

Polymorphonuclear leukocyte functions were measured in adult burn patients during the first three weeks post burn.

Bactericidal capacity for *S. aureus* was studied by a modification of the Maaloe method (54, 62). Neutrophil leukocytes were separated from heparinized blood with dextran and incubated with a log phase culture of *S. aureus* at a bacteria to PMN ratio of 1:1. The bactericidal capacity was expressed as the percentage of the original number of bacteria killed after 120 minutes' incubation.

Chemotaxis experiments were performed with a modified Boyden technique (38). Neutrophil leukocytes were separated by heparin sedimentation, and deposited on a 5 µm Millipore filter. The filter was placed in a modified Boyden chamber containing crude *Escherichia coli* toxin as a chemotactic agent. The chemotactic index was the patient/control ratio for the numbers of PMN that had migrated completely through the filters.

Experimental investigations of fabrics and clothes (II, IV, V)

Physical properties

The function of fabrics as air filters was measured with quartz dust and room air. Electrostatic charge propensity was also tested. The water absorption of some fabrics was investigated with a Swedish standard method (SIS 25 12 28).

A new instrument for measuring bacterial penetration (V)

An instrument, consisting of a turntable rotating at a constant speed and a teflon ball rubbed against the rotating surface, was built. Pieces of cloth, contaminated through use in burn patient nursing, were rubbed against pieces of the fabric to be tested. Bacteria that penetrated the test fabric were sampled on Millipore filters or blood agar. The penetration through the test fabric when dry and when wet was measured by colony count on the sampling surfaces after incubation.

Standardized exercise (II)

A technician wore a gown, contaminated during burn patient care, over a barrier garment, and underneath both a sterile cotton suit. She then carried out a standardized exercise (75 golf swings). The efficacy of the barrier garment was expressed as the ratio of contamination on the cotton suit jacket to that of the contaminated source gown (35).

Mock nursing (II, IV)

One barrier garment of the type to be tested was worn by a nurse during a morning nursing of a burn patient. This nurse wore a sterile cotton suit underneath the barrier garment. Afterwards, this cotton suit was donned by a mock nurse. Over the contaminated cotton suit, the mock nurse dressed in a new barrier garment of the same type as used by the real nurse. She then carried out a nursing of a mock patient who wore sterile clothes. The efficacy of the barrier garment was measured by: a) the contamination of the real nurse's suit jacket, b) the contamination of the air of the mock patient's room, and c) the contamination of the mock patient's clothes and bed.

Clothes and clothing routines (II, III, IV)

Cotton suit consisting of jacket and trousers of cotton/polyester was the working dress in the ward, laundry clean each day.

Cotton gown was an ordinary sterile operating room gown, made of green cotton. The cotton suits and gowns were taken from the ward storage, and had been worn and washed an indeterminate number of times.

Tyvek gown, loose coverall and close coverall (Fig. 2) were garments specially designed for the study, made of spun-bonded polyethylene fibre. They were washed, autoclaved and re-used twice.

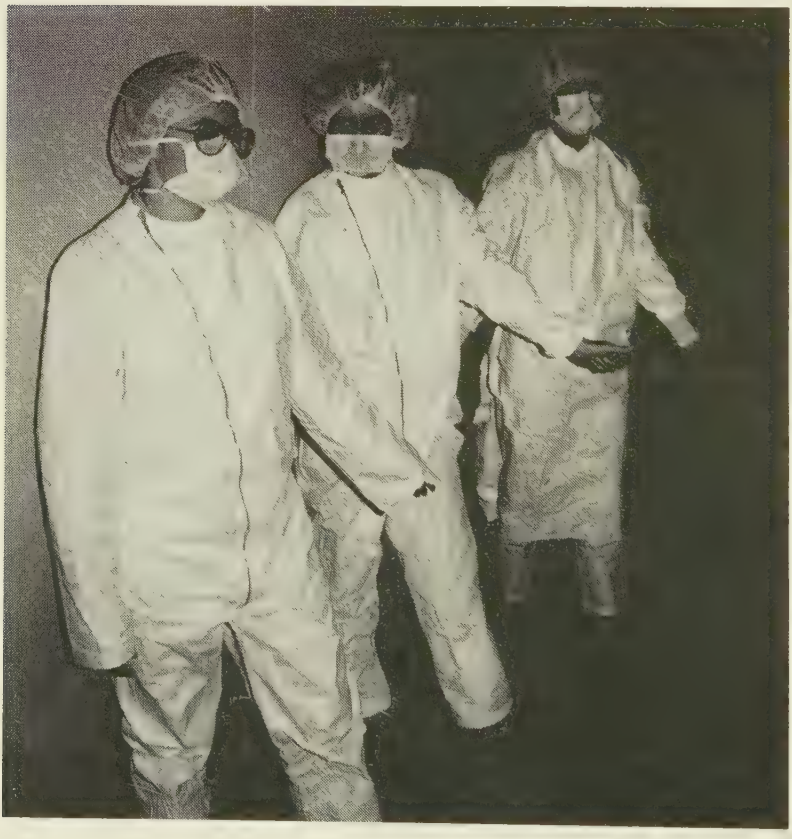

Fig. 2 The Tyvek gown, loose coverall and close coverall.

Apron and gloves. A disposable polyethene apron, and shoulder-length gauntlets, were worn during nursing through the isolator wall. One series of experiments with mock nursing were also carried out with this barrier dress only.

Barrier garments were always worn with cap, mask and sterile gloves, and over the cotton suit. In the clinical study (III), four clothing routines were tried in alternating periods.
During the control period cotton gowns were used on all visits to the patients.
In the strip period, cotton gowns were used only when nursing implied close contact with the patients. The cotton gown and the cotton suit worn underneath were changed after each close nursing. On other visits to the patient room, a cotton suit only was worn.
In the tyvek period, a tyvek close coverall was used during close nursing and discarded afterwards but the cotton suit was kept on. Other routines were as in the strip period.
In the green period, a cotton gown was used for close nursing. The cotton suit worn underneath was kept on all day. Other routines were as in the strip period.

The isolator (IV)

An open-roofed patient isolator (Fig. 3), made with aluminium profiles and polyvinyl chloride foil, was erected in an isolation room in the burn unit. It had movable lateral walls with access to the patient through overlapping flaps. Nurses working with the isolator wore plastic aprons and shoulder-length gauntlets.

The isolator was investigated with airborne tracer particles, with mock nursing and with patient trials.

Airborne tracer particles (IV)

A spinning-disc particle generator was used to produce an aerosol of potassium iodide particles. The dispersal and transfer of such particles from one side of the isolator wall to the other was sampled with filters (30).

Fig. 3 An open-roofed plastic isolator.

RESULTS

Neutrophil leukocyte functions and wound bacteria (I)

The neutrophil leukocyte functions of sixteen burn patients were studied twice a week for the first three weeks post burn. Leukocytes from healthy female laboratory staff were used as controls in each experiment.

Bactericidal capacity for *S. aureus* (Fig. 4) was mean 92 % in the controls, (standard deviation (SD) 5 %, range 82-99 %). Six of the nine patients with a burn size of over 30 % had a bactericidal capacity of more than 1 SD below the mean on some occasion, and five of them below 2 SD. Six of the seven patients with smaller burns also had a lowered bactericidal capacity. Three of the four patients who died had a bactericidal capacity of more than 2 SD below the mean, and the fourth patient died on day six after injury. The mean time from injury to lowest bactericidal capacity was 14 days.

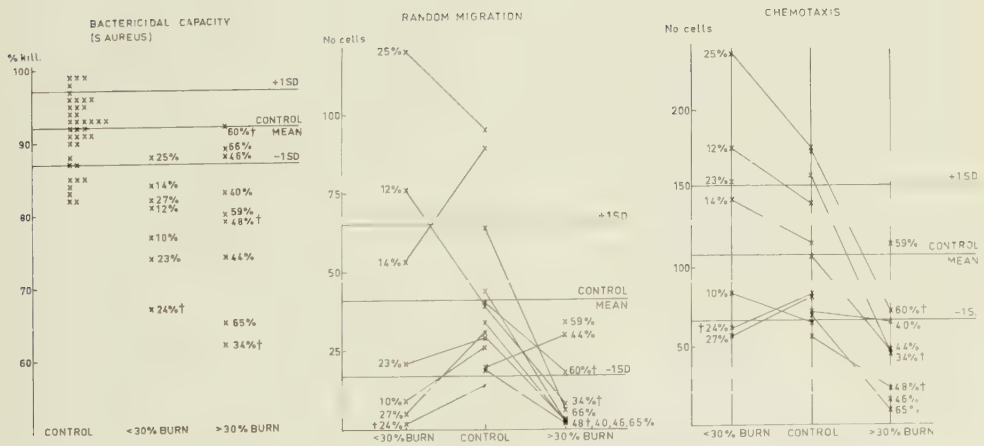

Fig. 4 Neutrophil leukocyte functions of burn patients and controls.

Neutrophil leukocytes from five of seven patients with small burns had random migration of less than 75 % of their controls, but the remaining two had lowest values of more than 125 % of their controls. Among patients with large burns, seven had random migration values of less than 35 % of their controls, although two had values equal to or higher than their controls (Fig. 4). The mean day for the lowest values was day nine.

The minimum values for chemotaxis of PMN were above 125 % of the controls for four of seven patients with small burns. The only patient with a small burn who died had a chemotaxis of less than 75 % of the control. Seven of the nine patients with large burns had values lower than 60 % of the experiment control, and the three patients who died had chemotaxis less than 45 % of the controls (Fig. 4). The lowest values occurred on day ten as a mean.

All the sixteen patients were colonised with *S. aureus* by the end of the first week after injury. *Ps. aeruginosa* colonised one patient with a small burn, who had bactericidal capacity of below 2 SD, a normal random migration and a high chemotaxis. The five patients with larger burns who were colonised with *Ps. aeruginosa* all had a low bactericidal capacity, and a low chemotaxis, and four of them also had a low random migration. The greatest impairment in leukocyte functions occurred within a few days of the appearance of *Ps. aeruginosa* in the burn wound in four of the six colonised patients, but two to three weeks earlier in the remaining two. The total amounts of bacteria in the burn wounds reached its maximum on day twelve as a mean. This maximal bacterial load and the minimum lowest values of the leukocyte functions occurred in the same week in fourteen of the sixteen patients investigated.

Experimental investigations of some clothes for barrier nursing (II)

Previous investigations had shown that common cotton gowns were not sufficiently effective to prevent the spread of infection from patient to patient in a burn unit (35).

Air filter tests were used to select a fabric that was better than common cotton such as used for gowns worn in the ward. One of the fabrics selected, a spun-bonded polyethylene material, was used for the design of new barrier garments. To evaluate the importance of the fit of a protective garment, a gown, a loose coverall and a close coverall were designed (Fig. 2). These three garments were tried in a standardized exercize and in mock nursing. The results were compared to those previously obtained in investigations of other garments with the same methods (35).

The performances of the new gown and loose coverall in standardized exercise were of the same order as that of the cotton gown. The transmission of marker *S. aureus* from burn patients through the garments was 1.7, 1.7, and 1.6 %, respectively.

In mock nursing, the counts of *S. aureus* on the nurse's jacket was five times lower with the close Tyvek coverall than with a cotton gown. Transfer of *S. aureus* from the real burn patient to the mock patient was 40-50 times lower with the cotton gown and 10-25 times lower with the new closer garments than without barrier garment. This comparison was based on the air counts in the burn patient's room as a measurement of the degree of the contamination on the nurse, which may not be quite correct (III). The amounts of *S. aureus* on the nurse's jacket that were transferred to the mock patient was of the same order with all the protective garments (Table I), except with the close new coverall when it was about two to three times higher. The transfer from the nurse's jacket to the air of the mock patient's room was low in all experiments, but seemed to be three to four times higher with the close coverall than with a looser garment made of the same fabric or of cotton.

Table I Transfer of *Staphylococcus aureus* via clothes

	No gown	Cotton gown	Tyvek loose coverall	Tyvek close coverall	Bar-bac (Ventile) gown	Isolator	Apron
Air filter tests							
Penetration of particles >1.0 µm from room air		48.6 %		2.5 %	0.5-23.2 %		
Mock nursing							
Counts on nurse's jacket	64 000	7 500	9 500	1 500	1 600	(8 300)	(36 000)
Transmission from jacket to mock patient	1.6 %	0.8 %	0.3 %	3.5 %	1.0 %	0.3 %	0.2 %
Air count in mock patient's room (c f u/m^3)	0.9	0.2	0.2	0.2	0.1	0.4	0.1
Transfer from jacket to air of mock patient's room (ratio x 10^{-6})	14	29	25	104	57	48	3
Clinical trial							
Air count of transferred strains (c f u/m^3)		2.4		1.5			
Colonisation rate with exogenous *S. aureus*		76 %		77 %			
Bacterial penetration							
Dry rubbing		14 %		14 %	2-15 %		<1 %
Wet rubbing		145 %		101 %	5-23 %		<1 %

Epidemiology and clothing routines in clinical use (III)

In a long-term study, the rates and routes of colonisations with *S. aureus*, *Streptococcus* groups A, B, C, F and G, and *Ps. aeruginosa* were investigated. In all, 111 patients were studied, and the environment in the burn ward was observed on 435 week days.

Staphylococcus aureus (Fig. 5)

Ninety-eight per cent of the patients were colonised with *S. aureus*. The exogenous colonisation rate was 77 %. About two thirds of these colonisations were caused by epidemic strains that gave at least three patient colonisations. Patients who had a *S. aureus* strain on admission that colonised their wound, acquired another strain in 71 % of the cases, as opposed to those who had no endogenous *S. aureus* colonisation where the exogenous colonisation rate was 94 %. The patients had a mean of two exogenous colonisations each (range 1-6). No attempt was made to differentiate between strains giving short-lived or more permanent colonisations. Seventy-four per cent of the traced exogenous colonisations were derived from patients.

The mean total counts of *S. aureus* in the patient room air was 30 c f u/m^3. Patients with large burns dispersed more of their *S. aureus* strains into the air of their rooms, but they were not more important as sources of colonisations than those who did not disperse their strains. Strains from patients were transferred into the air of other patients' rooms on two thirds of the observed days. Such transferred strains were often found in higher than average counts in air of the source patient's room, but in 12 % of the cases the source patient did not disperse the transferred strain. The concentration of *S. aureus* in the air of a disperser's room sometimes reached 500 c f u/m^3, but the median value for a dispersed strain was around 6 c f u/m^3. When a strain of *S. aureus* was transferred into the air of another patient's room and caused a colonisation, the number in the air of the receiving patient's room of the strain was less than 2 c f u/m^3 on 80 % of the occasions. The transferred strains found in the air of the patient rooms did not cause a greater proportion of the colonisations in the exposed patients than did other strains.

Fig. 5 Colonisation and dispersal of bacteria studied.

Beta-hemolytic Streptococcus (Fig. 5)

The colonisation rate with *Str. pyogenes* was 31 %, two thirds of which were endogenous. Eighty-nine per cent of the exogenous colonisations were derived from patients. Non-group A *Streptococcus* caused colonisations in 53 % of the patients. These were exogenous in 66 % of the cases. Eighty-eight per cent of the non-group A *Streptococcus* colonisations that were traced could be derived from patients. The mean number of colonisations with beta-hemolytic *Streptococcus* was 1.3 per colonised patient. As the streptococcal isolates were not M-typed, it was not possible to differentiate between colonisations with the same Lancefield group.

Sixty-nine per cent of the patients who were colonised with beta-hemolytic streptococci dispersed their strain into the air of their rooms in mean amounts of 20-25 c f u/m^3. Dispersers were present in the ward on one third of the observation days. The proportion of patients causing colonisations was equal among dispersers and non-dispersers (50 % versus 38 % for group A, and 58 % versus 53 % for other serogroups) and among patients with large and small burns. No transfer of streptococci from patients into the air of other patients' rooms could be detected. Streptococci did appear on settle plates in rooms where the patient nursed was not colonised, but they could always have come from staff and never caused a proven colonisation.

Pseudomonas aeruginosa (Fig. 5)

The overall colonisation rate with *Ps. aeruginosa* in the patients was 32 %. In patients with burns larger than 30 %, however, the colonisation rate was 60 %. Forty-five per cent of the colonisations could not be traced, and 16 % were proven to be endogenous. All the exogenous colonisations were derived from patients, and most of them were caused by epidemic strains giving 3-7 colonisations each.

Two thirds of the colonised patients dispersed their strains, in amounts of mean 2-3 c f u/m^3. Dispersers were present on 15 % of the observation days. Staff became transient nasal carriers of the dispersed strains on four occasions, but this was not shown to cause any patient colonisations. Transfer of *Ps. aeruginosa* into the air of patients' rooms occurred but rarely, and

was not an important cause of cross-colonisation. Eighty-one per cent of the dispersers had burns larger than 30 %, and so had 67 % of the colonised patients, as compared to 55 % of those who caused a colonisation.

Comparison of clothing routines

No differences in the overall colonisation rates with any of the bacteria studied could be detected between the periods. The appearance of the first exogenous *S. aureus* colonisation, however, was delayed from day 6-7 in the other periods to day 14 in the strip period. This difference was statistically significant ($P < 0.005$) when submitted to analysis of covariance with correction for age and burn size of the patients.

The median airborne transfer of *S. aureus* seemed paradoxically greater in the strip period than in the others, but this was probably a reflection of lower total air counts in that period which may have made it easier to detect single colonies of transferred strains. The mean transfer, when adjusted for differences in air counts in source rooms was 10.7 c f u/m^3 in control, 7.9 in strip, 7.0 in tyvek and 4.7 c f u/m^3 in green periods. These figures do not differ significantly.

Thus, the new coverall that had given promising results in air filter tests and in experimental nursing, did not diminish the clothes-borne transfer of bacteria between burn patients. A new, simpler clothing routine using conventional barrier gowns but only during close contact nursing, did not increase the risk of colonisation for the patients. The only routine that gave an improvement in *S. aureus* colonisations was the one where a more thorough change of dress was practised, and not only the barrier gown but also the soiled working suit worn underneath it was discarded after close contact nursing.

Isolator and aprons (IV)

An open-roofed plastic isolator was designed and built in the burn unit. It was designed only to prevent contact transfer to see how much this could be reduced in a plenum ventilated single patient room. Plastic aprons and gauntlets were used during nursing in the isolator to prevent contact between nurse and patient through the access flaps in the side walls of the

isolator (Fig. 3). The isolator was investigated with airborne tracer particles simulating bacteria-carrying particles, with mock nursing and in a small patient study. The effects of plastic apron and gauntlets as the only protective measure against contact transfer of bacteria were also investigated in mock nursing.

Tracer particle experiments indicated that the isolator might prevent some spread of airborne particles out of but not into the isolator. This was not verified in mock nursing or in the patient study, where the air counts of bacteria were practically the same inside and outside the isolator. In mock nursing, the amounts of bacteria released from the nurse's contaminated cotton suit to the air was 19 times higher with the isolator than when apron and gauntlets were the only protective measure (Table I). The isolator was only studied as protective in mock nursing.

In the patient study, the function of the isolator both as protection against and containment of infection was observed. Two patients only were nursed in the isolator during the 18 months it was present in the ward. Both these patients acquired exogenous colonisations during their stay in the isolator, one with a strain of *Ps. aeruginosa* from another patient and the other with an epidemic strain of *S. aureus*. Neither of these strains were found in the air of the isolator before the colonisations appeared, and transfer must have been by contact. A *S. aureus* strain from an isolator patient was detected in another patient's room once, but did not give rise to a secondary colonisation. Thus, the isolator was not fully effective neither as protection nor as containment. Both isolator patients developed serious psychiatric complications from treatment in the isolator, and had to be removed into other rooms, one after sixteen and one after five days. Delivering nursing care in the isolator was time-consuming and cumbersome. This may have lead to breaks in the isolator routine. All these factors contributed to the interruption of the study after these two patients.

Aprons and gauntlets as the only protective clothing on top of the working dress gave as much protection to the mock patient in mock nursing as did the isolator (Table I). This clothing routine was much easier to handle and far less costly than the isolator.

An instrument for measuring bacterial penetration through fabrics (V)

An instrument was designed for rubbing bacteria from a contaminated piece of cloth against a piece of fabric intended for barrier garments and for sampling the bacterial penetration through the fabric.

In the investigation of fabrics in the dry state, the bacterial penetration was around 10 % through most materials, irrespective of what the air filter tests had shown. The electrostatic charge propensity of the fabrics had no influence on this (Table I).

The bacterial count from the contaminated source cloth appeared to be about two to three times higher when measured in the wet state than when dry (more than 33 000, and 15 000 c f u/m^2/15 min, respectively).

The bacterial penetration through wet materials rapidly reached 100 % in one group of fabrics, including common green cotton and the non-woven polyethylene used in the new coveralls as described above (66). The speed with which the maximum penetration was reached was parallel to the rate of water absorption, which was above 150 % of the fabric weight in these materials. Another group of fabrics had an intermediate bacterial penetration which did not reach its peak level of 40-50 % until after 45 minutes of sampling. This second group also had an intermediate water absorption of 60-100 %. The third group of fabrics, including closely woven water-proofed cotton (Ventile) (18) and a plastic-laminated non-woven cellulose + rayon disposable fabric (40), had a bacterial penetration of less than 5-6 %. The water uptake of these water-proofed cottons was around 25-27 %, but increased 3-4 times when the cloth was washed 10 times, and so did the bacterial penetration. In Fig. 6 is shown the contamination of the source cloth alone and transferred through a washed ventile L 24 after 10 x 15 minutes' sampling.

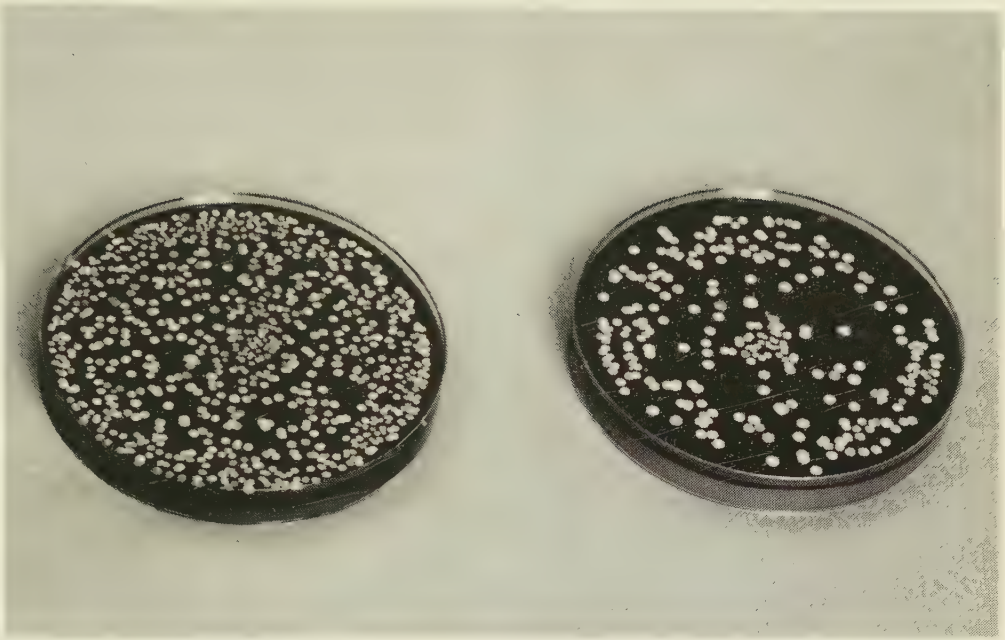

Fig. 6 Contamination of source cloth and transmission of bacteria through washed Ventile fabric.

DISCUSSION

Colonisation of the burn wound

The colonisation rates with *S. aureus* and beta-hemolytic streptococci were of the same order as those found in other burn units (10, 23, 73, 79, 81). The overall colonisation rate with *Ps. aeruginosa* seemed low, which had been attributed to a restrictive antibiotics policy in the ward, but the colonisation rate in patients with large burns was quite comparable to that found elsewhere (49).

Many patients had more than one colonisation with *S. aureus* of different phage patterns and/or beta-hemolytic *Streptococcus* of different serogroups. Colonisation with one strain, then, did not seem to protect against another colonisation, which has been postulated (4, 42, 80). That colonisations with many strains of the same species of bacteria were detected was due to frequent culturing from several sampling sites of the burn wound surfaces. This shows the need for careful monitoring of the burn wounds, both as guidance for antibiotic therapy and for epidemiological studies.

The majority of the exogenous colonisations were derived from patients. Staff as a source of exogenous colonisations was of minor importance, which is in agreement with findings in other investigations (33, 46). Some of the *S. aureus* colonisations, where no source was found, might have originated from staff, as perineal carriers among staff were not identified (17). A large proportion of the *Ps. aeruginosa* colonisations could not be traced. Stool cultures were only obtained from about one third of the patients, and no attempts were made at doing quantitative cultures, and so patient carriage of *Ps. aeruginosa* may have been underestimated (72).

Patients in need of protective isolation

Three quarters of the patients were colonised with exogenous *S. aureus*, irrespective of the burn size. The burn size distribution of those colonised with beta-hemolytic *Streptococcus* was also the same as in all patients admitted. Thus, burn size could not be used to predict which patients were at a risk of colonisation with these bacteria. *Ps. aeruginosa*, in contrast, more frequently colonised patients with large burns, as has previously been found (49), and those with poorly functioning leukocytes (1). Patients with

large burns have a higher letality risk (29). Even if their risk of acquiring a colonisation with streptococci or staphylococci is not increased, the growth of pathogenic bacteria in their wounds may constitute a greater hazard to the patients with large burns. This may be one reason to select patients with large burns for protective isolation.

Three quarters of the burn patients studied had malfunctioning leukocytes, both with regard to locomotion and killing of bacteria at some time during the first three weeks after injury (I). Patients with large burns had more serious disturbances in this respect than those with smaller burns, which is plausible if PMN functions were impaired by factors from the burn tissue (6) or from bacteria in the burn wound (57, 65, 67). Patients with small burns sometimes had activated leukocytes, in the same way as other patients with clinical infections (31, 37, 60). No raised bactericidal capacity was found in any of the patients, however, which may have been due to the fact that the leukocytes were not maximally challenged with bacteria (63).

To monitor leukocyte functions can be a useful guide in the selection of which burn patients to protect against infection (1, 32, 74). The middle of the second week after injury was the time when the leukocyte functions were most depressed. The total number of bacteria found in the burn wounds reached its maximum within the same week as the greatest impairment in leukocyte functions. It is impossible to tell which is cause and effect.

Patients in need of source isolation

Most of the exogenous colonisations were derived from patients with all the bacteria studied.

Patients with large burns dispersed more *S. aureus* to the air than did those with small burns, which agrees with previous findings (34). Dispersal of *Ps. aeruginosa* was considerable from large burns which has been little recognised before (43, 49, 53) but has been noted (10). Dispersal of beta-hemolytic *Streptococcus* also reached high concentrations in air, which has not previously been emphasized and was not correlated to burn size.

Transfer of bacteria into the air of patients' rooms could not have been primarily airborne but was probably carried via nurses' clothes, as shown before (35, 46). Spread of bacteria to the air was not shown to be an important route of cross-colonisations. The infective dose of *S. aureus* in the air was at least 30 times lower than that of 10^5 cells/m^2 needed to cause a colonisation in experimental infections (55). An additional dose by contact would be needed even in infection-prone burn patients. Cross-colonisation with beta-hemolytic *Streptococcus* and with *Ps. aeruginosa* was also transmitted mainly by contact as has been postulated before (10, 52, 58).

Dispersers and non-dispersers, and patients with large and small burns, were equally important as sources of colonisation with *S. aureus* and beta-hemolytic *Streptococcus* and with *Ps. aeruginosa* (Fig. 5). Thus burn size and dispersal of wound bacteria to the air could not be used to predict which patients constituted a hazard to their fellow patients as sources of colonisation. The degree of dispersal is not necessarily an indicator of how much contamination a burn patient offers to nurses' clothes. Patients with small burns that are not important as dispersers can cause considerable contact contamination of clothes when they need much handling - children, electric burns, etc.

The relative importance of airborne transfer of bacteria must be greater when several patients are nursed in the same room. In this investigation, the median dose of *S. aureus* in the air that a patient nursed in the same room as a dispersing burn patient would be exposed to was 30 c f u/m^3, but the dose could sometimes reach 500 c f u/m^3 and more. The higher dose corresponds to 6 x 10^5 *S. aureus* cells/m^2/24 h if each c f u is assumed to consist of four bacterial cells (48), which is well above the infective dose of 10^5 cells/m^2 needed to establish a clinical experimental infection in abraded skin (55). Dispersal to the air of burn patients' wound bacteria would probably be considerably diminished by topical chemotherapy and bandages (52). If antimicrobial agents in ointments and bandages are not effective enough to prevent the growth of bacteria in the burn wounds, the risk of contact contamination of nurses' clothes would still remain.

The development of better clothes and clothing routines for barrier nursing

In this investigation, the dose of *S. aureus* delivered from patient to patient by contact via clothes during 15 minutes (V) was 5-10 times larger than that transferred by air during 24 hours between patient rooms (III).

Experimental nursing

In experimental nursing, all the barrier garments reduced the contamination transmitted to the clothing worn underneath them by a factor of about 10 (range 5-30) (II). The effect of the isolator on such source isolation could not be investigated in mock nursing due to lack of patients (IV).

The transfer of bacteria from soiled clothes worn underneath a barrier garment to a mock patient was very little reduced by a more particle-tight fabric (II). This may have been due to a selection of bacteria-carrying particles: those who had passed through the pores of one piece of barrier garment down to the clothes worn underneath must have had a size that enabled them to pass from those clothes out through another piece of barrier garment of the same sort.

A tightly fitting garment released to the air four to five times as many of the bacteria from the clothes worn underneath as did a more loosely cut garment of the same material (II). This may have been due to increased friction between the pieces of clothing (64). The same phenomenon was found in the comparison between nursing with and without the isolator when nurses wore plastic apron and gauntlets. There, the release from the clothes was nearly 20 times higher during nursing with the isolator, where the nurse was continuously moving against the isolator wall.

The increased release of bacteria by more tightly fitting garments from clothes worn underneath them has not previously been discussed, although it has been shown that clothes may increase dispersal from carriers of *S. aureus* (39). This is contrary to previous opinions that closely fitting clothes were of advantage for the prevention of transfer of bacteria (13, 15, 39, 78). It indicates that the use of extra layers of clothing such as barrier garments should be restricted to times of heavy contact contamination only (see below).

Clinical trials

In clinical trials of the clothes investigated experimentally (III), a less rigid routine than that previously used did not increase the risk of cross-colonisation, although no barrier garment nor masks, caps or shoe covers were used except during close contact nursing. This has also been shown in isolation wards for newborns (28). One explanation might be that the contamination of clothes during other tasks in the patient room than those giving close contact was of little importance. Or else, the increased release of bacteria by the wearing of many layers of clothing might outnumber the possible beneficiary effects of a barrier gown when the risk of contamination was low. That close contact did give a high contamination was clearly shown in the measurements of bacterial counts on pieces of cotton that had been pinned on to the front of a gown worn for a morning nursing in the ward (V).

The wearing of a new coverall did not diminish the transfer of bacteria between burn patients, although the fabric used had seemed promising in air filter tests. The only clothing routine that gave any effects on the degree of cross-contamination was the one where not only the barrier gown but also the working clothes worn underneath it were changed after close contact nursing. One reason for this was probably that the penetration of bacteria through fabrics increases when they are wet (11). Clothes used in burn-patient nursing and in surgery often become wet with blood and sweat and wound secretions.

As transfer of bacteria between burn patients is so common, an overall reduction of *S. aureus* colonisation rates may be difficult to achieve. What might be easier to obtain is a delay in the time to colonisation as was shown in the clinical study (III). This may be of importance, since time is gained for the patient to recover from some of the immediate post-burn disturbances. The delay of the day of first exogenous *S. aureus* colonisation in the clothing routine with the most complete change of dress from day 6-7 to day 14 should be correlated to the mean day for the greatest impairments in neutrophil leukocyte functions which was on days 9-10-14 (I).

Measurements of bacterial penetration through fabrics with a new instrument

The results from experimental investigations of clothes (II) diverged from the effects of the same clothes in the clinical study (III). One reason for this could be that the methods used for experimental testing were inadequate. The mechanisms by which bacteria pass through fabrics may not be with passage of air, which is tested in filter tests. Clothes are bent and stretched during nursing, and several layers of clothes are rubbed against each other, which may release bacteria (24, 64). Such mechanisms were applied in the new instrument (V). The results of measurements of bacterial penetration through dry materials showed that most fabrics reduced the transmission to about 10 %, irrespective of the results of air filter tests. This is well in agreement with the results of experimental nursing.

The properties of clothes can change when wet (11, 24). This could be a reason why the clinical trials of clothes gave even less effects on the prevention of transfer of bacteria than the experimental nursing had led to believe. In wet measurements, counts from the contaminated source cloth appeared to be two to three times higher than in the dry measurements. This was probably because the microcolonies consisting of 3-4 cells present on the cloth (48) were more highly separated in the wet cloth where they became suspended in the fluid (41). The results of measurements of bacterial penetration through wet materials showed that all the fabrics for clothes in the clinical trial when wet let through about 100 % of the bacteria they were contaminated with. The water absorption rate was very high in these fabrics, including non-woven polyethylene. Fabrics with a lower water absorption rate, and with small pores, showed a lower penetration of bacteria.

The largest pore diameter in most fabrics used for protective clothing was over 20 µm (47). To prevent the penetration of microcolonies of just a few bacterial cells (48) in a fluid suspension, the fabric would probably have to be practically non-porous, as the size of one *S. aureus* cell is less than 2 µm (8). A very closely woven water-proofed cotton where the fibres swell and close the pores when wet, or a plastic-laminated fabric might be needed.

An isolator

A plastic isolator, such as has been described before (7, 20, 52) would theoretically fulfil the above requirements. All the workers cited met with difficulties in the application of an isolator system in practice. In the study where the results of nursing in an isolator seemed most favourable (20), many other factors such as early excision and grafting of the burn wound and topical chemoprophylaxis (21) may have contributed to the good results.

In the present investigation (IV), the results of mock nursing with an open-roofed plastic isolator designed specifically to prevent contact contamination only, were not as good as had been hoped. As expected, it had no effect on airborne transfer of bacteria. In mock nursing, the protection was of the same order as that given by apron and gauntlets.

The two patients that were nursed in the isolator both acquired exogenous colonisations from patients, one with *S. aureus* and one with *Ps. aeruginosa*, which must have been transmitted by contact. These results are even poorer than those of previous workers, who have thought isolators of limited value except in the control of *Ps. aeruginosa* (52).

The isolator was cumbersome and difficult to work with, which agrees with previous findings (20, 52). Both patients developed psychiatric complications from treatment in the isolator, which is also a phenomenon well known before (75).

All these factors contributed to the early interruption of the isolator study. They make it unlikely that an isolator should be a realistic alternative in isolation care for burn patients in single rooms.

The applicability of the results on nursing in other isolation wards

The mean counts of *S. aureus* in occupied patient rooms of this burn unit was three to ten times higher than that found in open general wards (46) (30 c f u/m^3 as compared to 3-11 c f u/m^3). Nursing a patient in the same room as a dispersing burn patient would constitute a real risk of colonisation from the air to the exposed patient. Even with the greater dispersal from burn patients, nursing in single rooms with plenum ventilation effec-

tively prevented the transfer of bacteria via the air from patient to patient. Thus, such isolation rooms would be sufficient to prevent airborne transfer also between other types of infectious and infection-prone patients, and little can probably be gained by the further increase of ventilation in patient rooms.

When the risk of airborne spread of bacteria has been eliminated by isolation rooms and other important measures such as hand hygiene and no-touch surgical techniques (50) are applied, the remaining major route of cross-contamination is via clothes.

Burn patients do not only disperse more bacteria to the air of their rooms but also have higher infection rates than ordinary surgical patients (19, 33). The degree of contact contamination offered to nurses' clothes from burn patients may be greater than from patients with wound or skin infections of lesser extent, but this has not been investigated. That contamination of clothes can reach high values elsewhere than in burn wards is well known (24).

Unnecessary wear of extra layers of clothing may increase the risk of contamination, as shown in the present study. The wearing of barrier garments should be restricted to times of close contact only. This may make the delivery of barrier nursing less cumbersome and costly. To concentrate the efforts of protection upon what happens during close contact between nurse and patient, then, seems to be the most important way to combat cross-contamination. In that situation, the barrier garments worn should not be tightly fitting but must be practically impermeable to fluids and bacteria.

CONCLUSIONS

1. Burn patients have malfunctioning polymorphonuclear leukocytes (PMN), particularly during the first and second week after injury, which coincides with the maximum growth of bacteria in the burn wound. The monitoring of PMN functions can give guidance as to when the patients need protective isolation.

2. Colonisation rates with *S. aureus* and beta-hemolytic *Streptococcus* are equal in patients with large and small burns. Patients with large burns run a greater risk of acquiring a colonisation with *Ps. aeruginosa*. Thus, burn size can to some extent predict which patients need protective isolation.

3. Patients with large burns often disperse *S. aureus* and *Ps. aeruginosa* to the air of their rooms. Beta-hemolytic *Streptococcus* are also dispersed. Airborne transfer of bacteria is of little importance as a cause of cross-contamination between plenum ventilated isolation rooms. In such rooms, transfer of bacteria is mainly via clothes contaminated by contact. Patients with small burns can be important sources of contact contamination although they disperse little bacteria to the air.

4. A thorough change of nurses' clothes after close contact nursing delayed the first exogenous *S. aureus* colonisation from the first to the second week post burn, that is, after the maximum impairment of PMN functions. A further reduction in cross-contamination would be possible with barrier garments impermeable to fluids and bacteria on points of contact, as indicated by experiments with plastic apron and gauntlets as only protective dress.

5. Measurements of penetration through fabrics of particles suspended in air, commercially used, did not correlate to the performance of garments made from the fabrics in experimental nursing and clinical use. An instrument was designed to measure penetration of bacteria through fabrics by rubbing. Bacteria were shown to penetrate dry fabrics at a rate of about 10 %, irrespective of air filter tests. When wet, the microcolonies pre-

sent on the cloth were separated into smaller units, and the penetration of bacteria rapidly increased up to 100 % except in water-proofed or plastic-laminated fabrics. These results are in agreement with findings in experimental nursing, and in clinical use, respectively. Thus, such measurements can be used to select fabrics for barrier garments.

6. Tightly fitting barrier garments increased the dispersal of bacteria from clothes worn underneath them 3-20 times, probably by friction. The wearing of barrier garments should therefore be restricted to close contact nursing, when the risk of contact contamination outnumbers the risk of redispersal of bacteria from clothes.

7. An open-roofed plastic isolator, designed and built in the burn unit, did not appreciably reduce cross-contamination, and gave psychological and practical problems. It seems not to be a realistic alternative to better protective garments in isolation rooms.

ACKNOWLEDGEMENTS

My sincere thanks are due to

Professor Gunnar Laurell who initiated the investigation and constantly led and supported me throughout the work,

Ass. Professor Folke Nordbring who was my first teacher in the field of infectious diseases,

Ass. Professor Anna Hambraeus in whose footsteps on the road to burn unit hygiene I followed and who guided my way,

Professors Bengt Pontén and Gösta Arturson and their co-workers in the burn unit at Akademiska sjukhuset who vividly discussed and patiently participated in the investigations,

Professor Arne Forsgren and Ass. Professor Stellan Bengtsson who discussed with me at length the production of my papers and other things,

Ms Ulla Zettersten, Ms Anita Björkvall, Ms Anneli Lantz, Ms Eva-Lena Fock, and many others who with expert knowledge performed the laboratory work,

Ms Zohra Zabielski and Mr Michael Wilcox who gave linguistic advice,

Ms Christina Blomberg who edited and produced the manuscript and without whom you would not be able to read this,

and friends and relations who stood by me.

The work was supported by grants from the Swedish National Defense Research Institute and from the Faculty of Medicine, Uppsala University.

REFERENCES

1. Alexander, J.W. & Meakins, J.L.: A physiological basis for the development of opportunistic infections in man.
Ann Surg 176: 273, 1972.

2. Alford, D.J., Ritter, M.A., French, M.L.V. & Hart, J.B.: The operating room gown as a barrier to bacterial shedding.
Am J Surg 125: 589, 1973.

3. Altemeir, W.A.: Current infection problems in surgery.
Proc Internat Conf on Nosocomial Infection, Waverly Press Inc., Baltimore 1971.

4. Aly, R., Maibach, H.I., Shinefield, H.R., Mandel, A. & Strauss, W.G.: Bacterial interference among strains of Staphylococcus aureus in man.
J Inf Dis 129: 720, 1974.

5. Arturson, G., Högman, C.F., Johansson, S.G.O. & Killander, J.: Changes in immunoglobulin levels in severely burned patients.
Lancet i: 546, 1969.

6. Asko-Seljavaara, S., Sundell, B. & Rytömaa, T.: The effect of early excision on bone-marrow cell growth in burned mice.
Burns 2: 140, 1976.

7. Babb, J.R., Bridges, K., Lowbury, E.J.L., Hodgson, E.M. & Trexler, P.C.: A source isolator for infected patients.
J Hyg (Camb) 76: 355, 1976.

8. Baird-Parker, A.C.: Classification and identification of staphylococci and their resistance to physical agents.
In: The Staphylococci, p. 4 (ed. J.O. Cohen), Wiley-Interscience 1972.

9. Balch, H.H.: Resistance to infection in burned patients.
Ann Surg 157: 1, 1963.

10. Barclay, T.L. & Dexter, F.: Infection and cross infection in a new burns centre.
Br J Surg 55: 197, 1968.

11. Beck, W.C. & Carlson, W.W.: Aseptic barriers.
Arch Surg 87: 288, 1963.

12. Bengtsson, S., Hambraeus, A. & Laurell, G.: Wound infections after surgery in a modern operating suite. Clinical and epidemiological findings.
In manuscript 1978.

13. Bernard, H.R., Speers, R., O'Grady, F. & Shooter, R.A.: Reduction of dissemination of bacteria by modification of operation room clothing and ultraviolet radiation.
Lancet ii: 458, 1965.

14. Blair, J.E. & Williams, R.: Phage-typing of staphylococci.
Bull W H O 24: 771, 1961.

15. Blowers, R. & McCluskey, M.: Design of operating room dress for surgeons.
Lancet ii: 681, 1965.

16. Bodey, G.P.: Isolation for the compromised host.
J Am Med Ass 233: 543, 1975.

17. Böe, J., Solberg, C.O., Vogelsang, T.M. & Wormnes, A.: Perineal carriers of staphylococci.
Br Med J ii: 280, 1964.

18. Brigden, R.J.L.: A water-repellent theatre drape. Reproofing ventile fabric.
Nursing Times 60: 1651, 1964.

19. Bröte, L. & Nilehn, B.: Wound infections in general surgery with special reference to the occurrence of Staphylococcus aureus.
Scand J Inf Dis 8: 89, 1976.

20. Burke, J.F.: The management of contamination in burns. A new look at isolation techniques.
J Saint Barnabas Medical Centre 9: 11, 1972.

21. Burke, J.F., Bondoc, C.C. & Quinby, W.C.: Primary burn excision and immediate grafting: a method shortening illness.
J Trauma 14: 389, 1974.

22. Cars, O., Forsum, U. & Hjelm, E.: New immunofluorescence method for the identification of group A, B, C, E, F, and G streptococci.
Acta Pathol Microbiol Scand (B) 83: 145, 1975.

23. Cason, J.S., Jackson, D.M., Lowbury, E.J.L. & Ricketts, C.R.: Antiseptic and aseptic prophylaxis for burns: Use of silver nitrate and of isolators.
Br Med J iv: 1288, 1966.

24. Charnley, J. & Eftekhar, N.: Penetration of gown material by organisms from the surgeon's body.
Lancet i: 172, 1969.

25. Charnley, J.: Postoperative infection after total hip replacement with special reference to air contamination in the operating room.
Clin Orthop 87: 167, 1972.

26. Colebrook, L.: A new approach to the treatment of burns and scalds.
Fine Technical Publications, London 1950.

27. Craddock, P.R., Yawata, Y., VanSanten, L., Gilberstadt, S., Silvis, S. & Jacob, H.S.: Acquired phagocyte dysfunction. A complication of the hypophosphatemia of parenteral hyperalimentation.
N Engl J Med 290: 1403, 1974.

28. Evans, H.E., Akpata, S.O. & Baki, A.: Bacteriologic and clinical evaluation of gowning in a premature nursery.
J Pediatr 78: 883, 1971.

29. Feller, I. & Jones, C.A.: Nursing the burned patient, p. 11.
Braun-Brumfield, Inc., Ann Arbor, Michigan 1973.

30. Foord, N. & Lidwell, O.M.: The control by ventilation of airborne bacterial transfer between hospital patients, and its assessment by means of a particle tracer. I. An airborne-particle tracer for cross-infection studies.
J Hyg (Camb) 70: 279, 1972.

31. Gallin, J.I. & Wolff, S.M.: Leukocyte chemotaxis: Physiological considerations and abnormalities.
Clinics in Haematology 4: 567, 1975.

32. Grogan, J.B.: Altered neutrophil phagocytic function in burn patients.
J Trauma 16: 734, 1976.

33. Hambraeus, A.: Studies on transmission of Staphylococcus aureus in an isolation ward for burned patients.
J Hyg (Camb) 71: 171, 1973.

34. Hambraeus, A.: Dispersal and transfer of Staphylococcus aureus in an isolation ward for burned patients.
J Hyg (Camb) 71, 787, 1973.

35. Hambraeus, A.: Transfer of Staphylococcus aureus via nurses' uniforms.
J Hyg (Camb) 71: 799, 1973.

36. Hambraeus, A. & Sanderson, H.F.: The control by ventilation of airborne bacterial transfer between hospital patients, and its assessment by means of a particle tracer. III. Studies with an airborne particle tracer in an isolation ward for burned patients.
J Hyg (Camb) 70: 299, 1972.

37. Hill, H.R., Gerrard, J.M., Hogan, N.A. & Quie, P.G.: Hyperactivity of neutrophil leukotactic responses during active bacterial infection.
J Clin Invest 53: 996, 1974.

38. Hill, H.R., Hogan, N.A., Mitchell, T.G. & Quie, P.G.: Evaluation of a cytocentrifuge method for measuring neutrophil granulocyte chemotaxis.
J Lab Clin Med 86: 703, 1975.

39. Hill, J., Howell, A. & Blowers, R.: Effect of clothing on dispersal of Staphylococcus aureus by males and females.
Lancet ii: 1131, 1974.

40. Hoborn, J.: Mensch, Bekleidung und Reinraumtechnik.
Medita 7: 3, 1977.

41. Holt, R.J.: Aerobic bacterial counts on human skin after bathing.
J Med Microbiol 4: 319, 1971.

42. Hughes, W.H.: The irreducible minimum in cross-infection control and isolation nursing.
J Hyg (Camb) 68: 379, 1970.

43. Kominos, S.D., Copeland, C.E. & Grosiak, B.: Mode of transmission of Pseudomonas aeruginosa in a burn unit and an intensive care unit in a general hospital.
Appl Microbiol 23: 309, 1972.

44. Levenson, S.M., Trexler, P.C., LaConte, M. & Pulaski, E.J.: Application of the technology of the germfree laboratory to special problems of patient care.
Am J Surg 107: 710, 1964.

45. Lidwell, O.M.: Unidirectional ("laminar") air flow for ventilation of patient rooms.
In: Airborne transmission and airborne infection, p. 534. Oosthoek Publishing Company, Utrecht 1973.

46. Lidwell, O.M., Brock, B., Shooter, R.A., Cooke, E.M. & Thomas, G.E.: Airborne infection in a fully air-conditioned hospital. IV. Airborne dispersal of Staphylococcus aureus and its nasal acquisition by patients.
J Hyg (Camb) 75: 445, 1975.

47. Lidwell, O.M. & Mackintosh, C.A.: Properties of fabrics in relation to their use as protective garments in nursing and surgery.
In manuscript 1977.

48. Lidwell, O.M., Noble, W.C. & Dolphin, G.W.: The use of radiation to estimate the numbers of micro-organisms in airborne particles.
J Hyg (Camb) 57: 299, 1959.

49. Liljedahl, S.O., Malmborg, A.S., Nyström, B. & Sjöberg, L: Spread of Pseudomonas aeruginosa in a burns unit.
J Med Microbiol 5: 473, 1972.

50. Lister, J.: An address on the present position of antiseptic surgery.
Br Med J ii: 377, 1890.

51. Lowbury, E.J.L.: Infection associated with burns.
Postgrad Med J 48: 338, 1972.

52. Lowbury, E.J.L., Babb, J.R. & Ford, P.M.: Protective isolation in a burns unit: the use of plastic isolators and air curtains.
J Hyg (Camb) 69: 529, 1971.

53. MacMillan, B.G., Edmonds, P., Hummel, R.P. & Maley, M.P.: Epidemiology of Pseudomonas in a burn intensive care unit.
J Trauma 13: 627, 1973.

54. Maaloe, O.: On the relation between alexin and opsonin.
Munksgaard, Copenhagen 1946.

55. Marples, R.R. & Kligman, A.M.: Experimental staphylococcal infections of the skin of man.
Zentralbl Bakteriol Suppl 5: 755, 1975.

56. Moncrieff, J.A.: Burns
N Engl J Med 288: 444, 1973.

57. Newsome, T.W. & Eurenius, K.: Suppression of granulocyte and platelet production by pseudomonas burn infection.
Surg Gynecol Obstet 136: 375, 1973.

58. Perry, W.D., Siegel, A.C. & Rammelkamp, C.H.: Transmission of group A streptococci. II. The role of contaminated dust.
Am J Hyg 66: 96, 1957.

59. Poplack, D.G., Penland, W.Z. & Levine, A.S.: Bacteriological isolation garment.
Lancet i: 1261, 1974.

60. Quie, P.G.: Bactericidal function of human polymorphonuclear leukocytes.
Pediatrics 50: 264, 1972.

61. Quie, P.G., Hill, H.R. & Davis, A.T.: Defective phagocytosis of staphylococci.
Ann N Y Acad Sci 236: 233, 1974.

62. Quie, P.G., White, J.G., Holmes, B. & Good, R.A.: In vitro bactericidal capacity of human polymorphonuclear leukocytes: diminished activity in chronic granulomatous disease of childhood.
J Clin Invest 46: 668, 1967.

63. Repine, J.E. & Clawson, C.C.: Quantitative measurement of the bactericidal capacity of neutrophils from patients and carriers of chronic granulomatous disease.
J Lab Clin Med 90: 522, 1977.

64. Rubbo, S.D. & Saunders, J.: Liberation of organisms from contaminated textiles.
J Hyg (Camb) 61: 507, 1963.

65. Russell, R.J., Wilkinson, P.C., McInroy, R.J., McKay, S., McCartney, A.C. & Arbuthnott, J.P.: Effects of staphylococcal products on locomotion and chemotaxis of human neutrophils and monocytes.
J Med Microbiol 8: 433, 1975.

66. Seaman, R.E. & Weimar, R.: Barrier properties of an air permeable, fine-fibre spun-bonded polyethylene sheet.
Unpublished, property of EI DuPont de Nemours & Co., Inc., Wilmington, Delaware 1973.

67. Sensakovic, J.W. & Bartell, P.F.: The slime of Ps. aeruginosa: biological characterization and possible role in experimental infection.
J Inf Dis 129: 101, 1974.

68. Sjöberg, L. & Lindberg, A.A.: Phage typing of Pseudomonas aeruginosa. Acta Path Microbiol Scand (B) 74: 61, 1968.

69. Smylie, H.G., Davidson, A.I.G., Macdonald, A. & Smith, G.: Ward design in relation to postoperative wound infection: part I. Br Med J 1: 67, 1971.

70. Solberg, C.O.: Enhanced susceptibility to infection. Acta Path Microbiol Scand (B) 80: 10, 1972.

71. Stossel, T.P.: Quantitative studies of phagocytosis. Kinetic effects of cations and heat labile opsonin. J Cell Biol 58: 346, 1973.

72. Sutter, V.L., Hurst, V. & Lane, C.W.: Quantification of Pseudomonas aeruginosa in feces of healthy human adults. Health Laboratory Services 2: 245, 1967.

73. Thomsen, M.: The burns unit in Copenhagen. VII. Time and onset and duration of infection. Scand J Plast Reconstr Surg 4: 61, 1970.

74. Warden, G.D., Mason, A.D. & Pruitt, B.A.: Evaluation of leukocyte chemotaxis in vitro in thermally injured patients. J Clin Invest 54: 1001, 1974.

75. Vejlsgaard, V. & Baek, L.: Psychological problems in patients during and after strict isolation. In: Proceedings of the 3'rd International Symposium on Contamination Control, p. 89, Copenhagen 1976.

76. Venge, P., Arturson, G. & Högman, C.F.: Serum inhibitors of PMN migration in severely burned patients. Plasmapheresis as a therapeutic possibility. Blood leukocytes - function and use in therapy, p. 51, Uppsala symposium 1977.

77. Whyte, W., Howie, J.G.R. & Eakin, J.E.: Bacteriological observations in a mechanically ventilated experimental ward and in two open-plan wards. J Med Microbiol 2: 335, 1969.

78. Whyte, W., Vesley, D. & Hodgson, R.: Bacterial dispersion in relation to operating room clothing. J Hyg (Camb) 76: 367, 1976.

79. Wickman, K.: Studies on burns. XIV: Bacteriology II. Acta Chir Scand Suppl 408, 1970.

80. Williams, R.E.O., Jevons, M.D., Shooter, R.A., Hunter. C.J.W., Girling, J.A., Griffiths, J.D. & Taylor, G.W.: Nasal staphylococci and sepsis in hospital patients. Br Med J 4: 658, 1959.

81. Wormald, P.J.: The effect of a changed environment on bacterial colonisation. J Hyg (Camb) 68: 633, 1970.